10/27/00 A

Case Docket No.: CORE-61

Assistant Commissioner For Patents
Washington, D.C. 20231

Sir:

Transmitted herewith for filing is the patent application of:

Inventor: Parviz Tayebati.
For: WAVELENGTH STABILIZATION OF TUNABLE LASERS BY CURRENT MODULATION.

Enclosed are:
☒ 5 sheets of drawings.
☐ An assignment of the invention to: _____.
☐ A verified statement to establish small entity status.
☐ _____.

The filing fee has been calculated as shown below:

			Small Entity		Large Entity	
For:	No. Filed	No. Extra	Rate	Fee	Rate	Fee
Basic Fee				$0.00		$710.00
Total Claims	6 - 20	0	x $ 9.00	0.00	x $18.00	0.00
Ind. Claims	3 - 3	0	x $40.00	0.00	x $ 80.00	0.00
Mult. Claims			+ $135.00		+ $270.00	
					Total	$710.00

☐ Please charge my Deposit Account No. 16-0221 to cover the filing fee and assignment recording fee. A duplicate copy of this sheet is enclosed.

☒ A check in the amount of $710.00 to cover the filing fee (~~and assignment recording fee~~) is enclosed.

☒ The Commissioner is hereby authorized to charge payment of the following fees associated with this communication or credit any overpayment to Deposit Account No. 16-0221. A duplicate copy of this sheet is enclosed.
- ☒ Any additional filing fees required under 37 CFR 1.16.
- ☒ Any patent application processing fees under 37 CFR 1.17.

☒ The Commissioner is hereby authorized to charge payment of the following fees during the pendency of this application or credit any overpayment to **Deposit Account No. 16-0221**. A duplicate copy of this sheet is enclosed.
- ☒ Any patent application processing fees under 37 CFR 1.17.
- ☐ The issue fee set in 37 CFR 1.18 at or before mailing of the Notice of Allowance, pursuant to 37 CFR 1.311(b).
- ☒ Any filing fees under 37 CFR 1.16 for presentation of extra claims.

Respectfully submitted,

Mary Pandiscio 10/26/00

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Tel. (781) 290-0060

MB/CORE61.FEE

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of: Parviz Tayebati
Title: WAVELENGTH STABILIZATION OF TUNABLE LASERS BY CURRENT MODULATION
Attorney's Docket No.: CORE-61

Date: October 26, 2000

BOX PATENT APPLICATION
Assistant Commissioner For Patents
Washington, D.C. 20231

Sir:

FILING OF PATENT APPLICATION UNDER 37 CFR 1.10

The attached application is being filed under the provisions of 37 CFR 1.10.

Applicant's attorney is also submitting the requisite fee as calculated on the attached transmittal letter.

Respectfully submitted,

Mark J. Pandiscio 10/26/00

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I HEREBY CERTIFY THAT THIS PAPER OR FEE IS BEING DEPOSITED WITH THE UNITED STATES POSTAL SERVICE "EXPRESS MAIL POST OFFICE TO ADDRESSEE" SERVICE UNDER 37 CFR 1.10 ON THE DATE INDICATED ABOVE AND IS ADDRESSED TO THE ASSISTANT COMMISSIONER FOR PATENTS, WASHINGTON, D.C. 20231.

MARK J. PANDISCIO
(PERSON MAILING)

Mark J. Pandiscio 10/26/00
(SIGNATURE)

APPLICATION

FOR

UNITED STATES LETTERS PATENT

PATENT APPLICATION

SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

Be it known that Parviz Tayebati of 2 Commonwealth Avenue, 15A, Boston, Massachusetts 02116 has invented certain improvements in WAVELENGTH STABILIZATION OF TUNABLE LASERS BY CURRENT MODULATION of which the following description is a specification.

MB/CORE61.CVR

WAVELENGTH STABILIZATION OF TUNABLE LASERS BY CURRENT MODULATION

Reference To Pending Prior Patent Application

This patent application claims benefit of pending prior U.S. Provisional Patent Application Serial No. 60/161,499, filed 10/26/99 by Parviz Tayebati for WAVELENGTH STABILIZATION OF TUNABLE LASERS BY CURRENT MODULATION (Attorney's Docket No. CORE-61 PROV), which patent application is hereby incorporated herein by reference.

Field Of The Invention

This invention relates to photonic devices in general, and more particularly to tunable lasers.

Background Of The Invention

In pending prior U.S. Patent Application Serial No. 09/105,399, filed 06/26/98 by Parviz Tayebati et al. for MICROELECTROMECHANICALLY TUNABLE, CONFOCAL, VERTICAL CAVITY SURFACE EMITTING LASER AND FABRY-PEROT

FILTER (Attorney's Docket No. CORE-33), and in pending prior U.S. Patent Application Serial No. 09/543,318, filed 04/05/00 by Peidong Wang et al. for SINGLE MODE OPERATION OF MICROMECHANICALLY TUNABLE, HALF-SYMMETRIC, VERTICAL CAVITY SURFACE EMITTING LASERS (Attorney's Docket No. CORE-53), which patent applications are hereby incorporated herein by reference, there are disclosed tunable Fabry-Perot filters and tunable vertical cavity surface emitting lasers (VCSEL's).

More particularly, and looking now at Fig. 1, there is shown a tunable Fabry-Perot filter 5 formed in accordance with the aforementioned U.S. Patent Applications Serial Nos. 09/105,399 and 09/543,318. Filter 5 generally comprises a substrate 10, a bottom mirror 20 mounted to the top of substrate 10, a bottom electrode 15 mounted to the top of bottom mirror 20, a thin support 25 atop bottom electrode 15, a top electrode 30 fixed to the underside of thin support 25, a reinforcer 35 fixed to the outside perimeter of thin support 25, and a confocal top mirror 40 set atop

thin support 25, with an air cavity 45 being formed between bottom mirror 20 and top mirror 40.

As a result of this construction, a Fabry-Perot filter is effectively created between top mirror 40 and bottom mirror 20. Furthermore, by applying an appropriate voltage across top electrode 30 and bottom electrode 15, the position of top mirror 40 can be changed relative to bottom mirror 20, whereby to change the length of the Fabry-Perot cavity, and hence tune Fabry-Perot filter 5.

Correspondingly, and looking next at Fig. 2, a tunable vertical cavity surface emitting laser (VCSEL) 50 can be constructed by positioning a gain medium 55 between bottom mirror 20 and bottom electrode 15. As a result, when gain medium 55 is appropriately stimulated, e.g., by optical pumping or by electrical pumping, lasing can be established between top mirror 40 and bottom mirror 20. Furthermore, by applying an appropriate voltage across top electrode 30 and bottom electrode 15, the position of top mirror 40 can be changed relative to bottom mirror 20, whereby to

change the length of the laser's resonant cavity, and hence tune laser 50.

The present invention is directed to tunable lasers of the type disclosed in the aforementioned U.S. Patent Applications Serial Nos. 09/105,399 and 09/543,318.

Tunable lasers of the type disclosed in the aforementioned U.S. Patent Applications Serial Nos. 09/105,399 and 09/543,318 are highly advantageous since they can be quickly and easily tuned by simply changing the voltage applied across the top electrode and the bottom electrode.

However, it has been found that tunable lasers of the type disclosed in the aforementioned U.S. Patent Applications Serial Nos. 09/105,399 and 09/543,318 can suffer from vibrational problems.

The aforementioned vibrational problems may be due to a variety of factors, such as thermal noise; or noise in the tuning voltage of the laser; or, in the case of an electrically pumped laser, shot noise in the injection current; etc.

Regardless of the cause, the effect of these vibrational problems is to cause the laser to move out of tune. In other words, these vibrational effects cause the output frequency of the laser to change even though the tuning voltage of the laser is held constant. While the extent of this vibration-related frequency shift may be relatively modest (e.g., a 300 MHz shift in the lasing frequency from a 100 MHz vibration frequency), this frequency shift may nonetheless create significant problems in certain types of systems, e.g., WDM communication systems.

See, for example, Fig. 3, which schematically illustrates how the aforementioned vibrational problems may cause a relatively periodic modulation of the lasing frequency; and Fig. 4, which schematically illustrates how the aforementioned vibrational problems may cause a relatively irregular modulation of the lasing frequency.

As a result, an object of the present invention is to provide a method and apparatus for stabilizing

the wavelength of tunable lasers affected by the aforementioned vibrational problems.

Summary Of The Invention

The present invention provides a fast and easy way to compensate for the aforementioned vibrational problems in tunable lasers, by correspondingly adjusting the electrooptical performance of the laser's gain medium, whereby to eliminate the frequency shift due to vibrational factors.

The electrooptical performance of the laser's gain medium is adjusted, in the case of an electrically pumped laser, by changing the injection current used to pump the laser; and the electrical performance of the laser's gain medium is adjusted, in the case of an optically pumped laser, by changing the intensity of the pump laser used to energize the laser.

The system is implemented with a feedback mechanism. A wavelength measuring module detects the difference between the instantaneous wavelength of the

laser and the desired wavelength of the laser, and generates a voltage signal which is representative of this difference. This voltage signal is then used to appropriately modify the electrooptical performance of the laser's gain medium, either by appropriately adjusting the injection current applied to the gain medium (in the case of an electrically pumped laser), or by appropriately adjusting the intensity of the pump laser applied to the gain medium (in the case of an optically pumped laser).

Brief Description Of The Drawings

These and other objects and features of the present invention will be more fully disclosed or rendered obvious by the following detailed description of the preferred embodiments of the invention, which is to be considered together with the accompanying drawings wherein like numbers refer to like parts and further wherein:

Fig. 1 is a schematic side view of a tunable Fabry-Perot filter;

Fig. 2 is a schematic side view of a tunable VCSEL;

Fig. 3 is a schematic diagram illustrating how the aforementioned vibrational problems may cause a relatively periodic modulation of the lasing frequency of a laser;

Fig. 4 is a schematic diagram illustrating how the aforementioned vibrational problems may cause a relatively irregular modulation of the lasing frequency of a laser;

Fig. 5 is a schematic diagram of a system for stabilizing the wavelength of an electrically pumped tunable laser; and

Fig. 6 is a schematic diagram of a system for stabilizing the wavelength of an optically pumped tunable laser.

Detailed Description Of The Preferred Embodiments

The present invention provides a fast and easy way to compensate for the aforementioned vibrational problems in tunable lasers, by correspondingly

adjusting the electrooptical performance of the laser's gain medium, whereby to eliminate the frequency shift due to vibrational factors.

More particularly, in a tunable laser of the sort disclosed in the aforementioned U.S. Patent Applications Serial Nos. 09/105,399, and 09/543,318, the output frequency of the laser may be affected by three variables, among others: (1) the tuning voltage applied to the laser, in the case of both electrically pumped and optically pumped lasers; (2) the injection current applied to the laser's gain medium, in the case of an electrically pumped laser; and (3) the intensity of the pump laser applied to the laser's gain medium, in the case of an optically pumped laser.

In particular, in the case of an electrically pumped laser, changing the injection current applied to the laser's gain medium causes a change in both the intensity of the laser's output and the output frequency of the laser. This is due to a corresponding change in the electrooptical performance of the laser's gain medium.

And in the case of an optically pumped laser, changing the intensity of the pump laser applied to the laser's gain medium causes a change in both the intensity of the laser's output and the output frequency of the laser. Again, this is due to a corresponding change in the electrooptical performance of the laser's gain medium.

The present invention is adapted to utilize one or the other of these phenomena, depending on whether the laser is electrically pumped or optically pumped, to selectively adjust the electrooptical performance of the laser's gain medium, whereby to eliminate the frequency shift due to the aforementioned vibrational factors.

More specifically, the present invention is adapted to (1) detect the frequency shift due to vibrational factors, and (2) compensate for this frequency shift by selectively modifying the electrooptical performance of the laser's gain medium, whereby to lock the laser to its target frequency. In the case of an electrically pumped laser, this

compensation is achieved by appropriately adjusting the injection current applied to the laser's gain medium; in the case of an optically pumped laser, this compensation is achieved by selectively adjusting the intensity of the pump laser applied to the laser's gain medium.

The system is implemented with a feedback mechanism. More particularly, a wavelength measuring module detects the difference between the instantaneous wavelength of the tunable laser and the desired wavelength of the laser, and generates a voltage signal which is representative of this difference. This voltage signal is then used to appropriately modify the electrooptical performance of the laser's gain medium, either by appropriately adjusting the injection current applied to the gain medium (in the case of an electrically pumped laser), or by appropriately adjusting the intensity of the pump laser applied to the gain medium (in the case of an optically pumped laser).

The particular wavelength measuring module used for the feedback mechanism can be any one of the many such devices well known in the art.

Looking now at Fig. 5, there is shown a preferred system for stabilizing the wavelength of an electrically pumped tunable laser 5. More particularly, the output of laser 5 is passed to a beamsplitter 10, where a portion of the laser's output is directed to a wavelength measuring module 15. Wavelength measuring module 15 is adapted to generate an output signal which is a function of the difference between the instantaneous wavelength of the tunable laser and the target wavelength of the laser. Preferably this output signal is in the form of a voltage signal whose magnitude varies according to the difference between the instantaneous wavelength of the tunable laser and the target wavelength of the laser. The output signal from wavelength measuring module 15 is then fed to a control unit 20, which modulates the pump current applied to tunable laser 5 according to the output signal of wavelength measuring module 15,

whereby to keep tunable laser 5 locked to its target frequency.

Correspondingly, and looking now at Fig. 6, there is shown a preferred system for stabilizing the wavelength of an optically pumped laser 5A. More particularly, the output of laser 5A is passed to a beamsplitter 10, where a portion of the laser's output is directed to a wavelength measuring module 15. Wavelength measuring module 15 is adapted to generate an output signal which is a function of the difference between the instantaneous wavelength of the tunable laser and the target wavelength of the laser. Preferably this output signal is in the form of a voltage signal whose magnitude varies according to the difference between the instantaneous wavelength of the tunable laser and the target wavelength of the laser. The output signal from wavelength measuring module 15 is then fed to a control unit 20, which modulates the pump current of a pump laser 25 according to the output signal of wavelength measuring module 15,

whereby to keep the tunable laser locked to its target frequency.

It is to be understood that the present invention is by no means limited to the particular constructions and method steps disclosed above and/or shown in the drawings, but also comprises any modifications or equivalents within the scope of the claims.

What Is Claimed Is:

1. Wavelength stabilizing apparatus for use in stabilizing the wavelength of a tunable laser to a target wavelength, the wavelength stabilizing apparatus comprising:

a wavelength measuring module for detecting the difference between the instantaneous wavelength of the laser and the target wavelength, and for generating an output signal which is representative of the same; and

a control unit for receiving said output signal from said wavelength measuring module and for modifying the electrooptical performance of the laser's gain medium in accordance with said output signal so as to lock the tunable laser to its target frequency.

2. Wavelength stabilizing apparatus according to claim 1 wherein the tunable laser is an electrically pumped laser, and further wherein said control unit is adapted to adjust the injection current applied to the

laser's gain medium so as to modify the electrooptical performance of the laser's gain medium.

3. Wavelength stabilizing apparatus according to claim 1 wherein said tunable laser is an optically pumped laser, and further wherein said control unit is adapted to adjust the intensity of the pump laser applied to the laser's gain medium so as to modify the electrooptical performance of the laser's gain medium.

4. Wavelength stabilizing apparatus according to claim 3 wherein the pump laser is an electrically pumped laser, and further wherein said control unit is adapted to adjust the injection current applied to the gain medium of the pump laser so as to modify the electrooptical performance of the tunable laser's gain medium.

5. A laser system comprising:

a tunable laser; and

wavelength stabilizing apparatus for use in stabilizing the wavelength of said tunable laser to a target wavelength, said wavelength stabilizing apparatus comprising:

a wavelength measuring module for detecting the difference between the instantaneous wavelength of the laser and the target wavelength, and for generating an output signal which is representative of the same; and

a control unit for receiving said output signal from said wavelength measuring module and for modifying the electrooptical performance of the laser's gain medium in accordance with said output signal so as to lock the tunable laser to its target frequency.

6. A method for stabilizing the wavelength of a tunable laser to a target frequency, said method comprising:

detecting the difference between the instantaneous wavelength of the laser and the target

wavelength, and generating an output signal which is representative of the same; and

modifying the electrooptical performance of the laser's gain medium in accordance with said output signal so as to lock the tunable laser to its target frequency.

Abstract

Apparatus and method for stabilizing the wavelength of a tunable laser to a target wavelength, by correspondingly adjusting the electrooptical performance of the laser's gain medium, whereby to eliminate the frequency shift due to vibrational factors. The electrooptical performance of the laser's gain medium is adjusted, in the case of an electrically pumped laser, by changing the injection current used to pump the laser; and the electrical performance of the laser's gain medium is adjusted, in the case of an optically pumped laser, by changing the intensity of the pump laser used to energize the laser. The system is implemented with a feedback mechanism.

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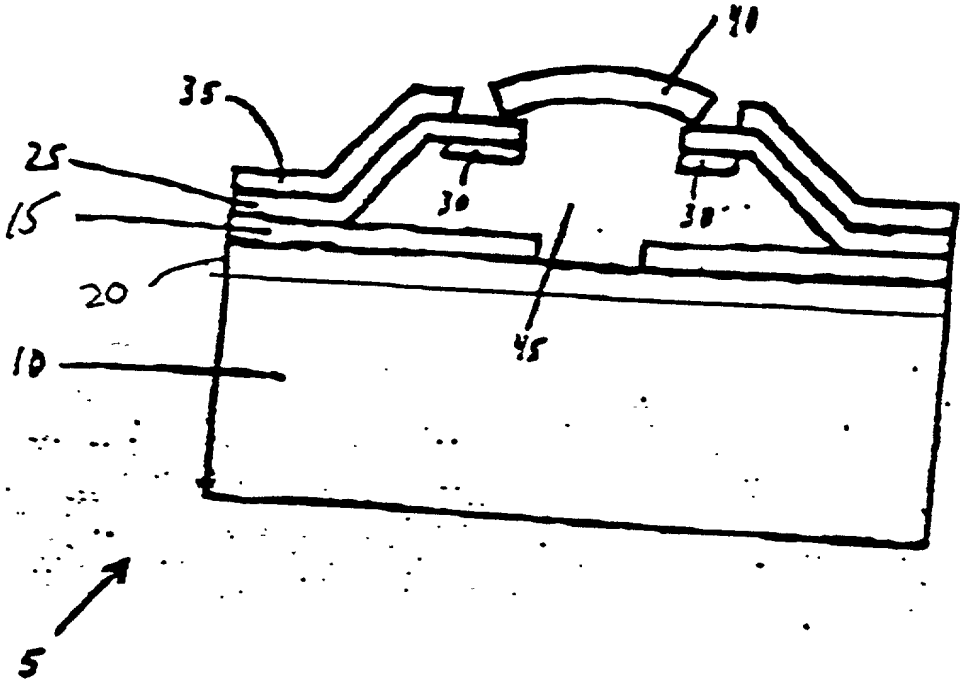

FIG. 1

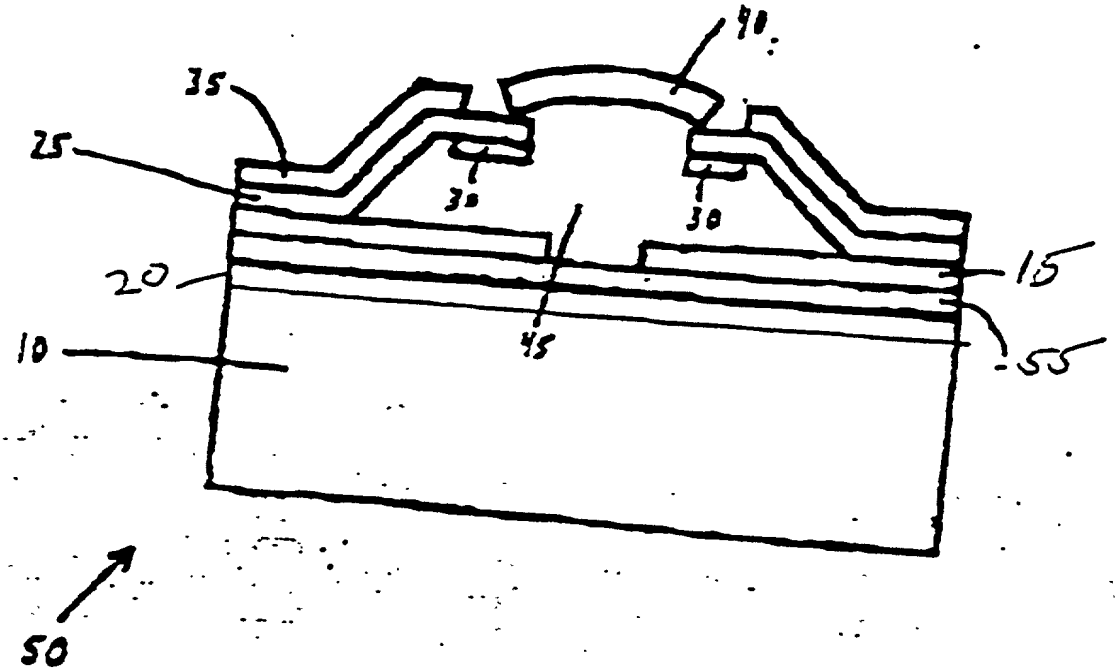

FIG. 2

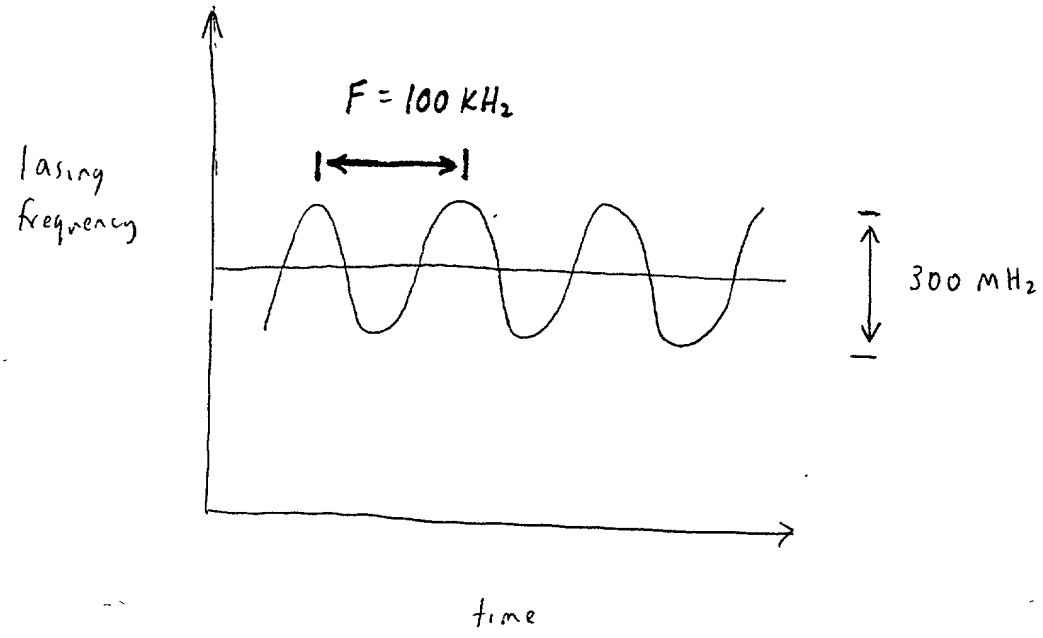
F = 100 KH₂
lasing frequency
300 MH₂
time

FIG. 3

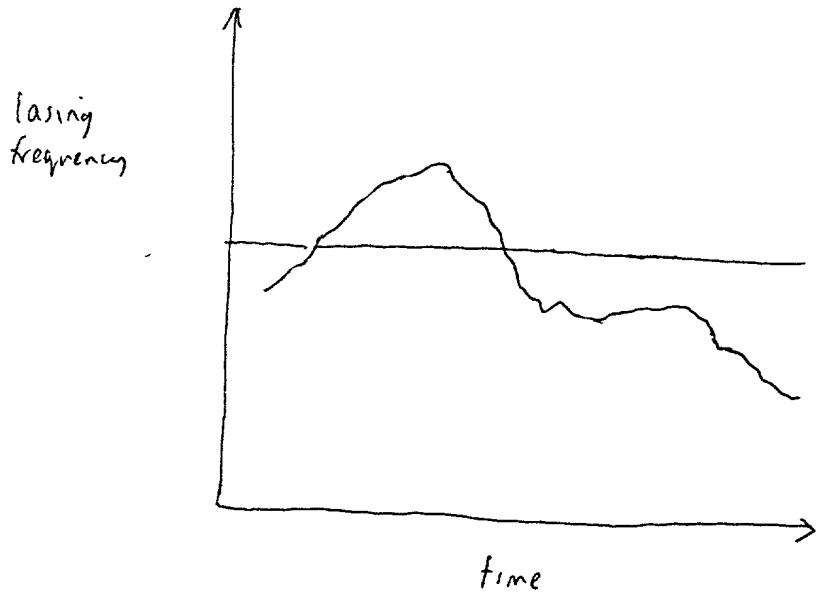
lasing frequency
time

FIG. 4

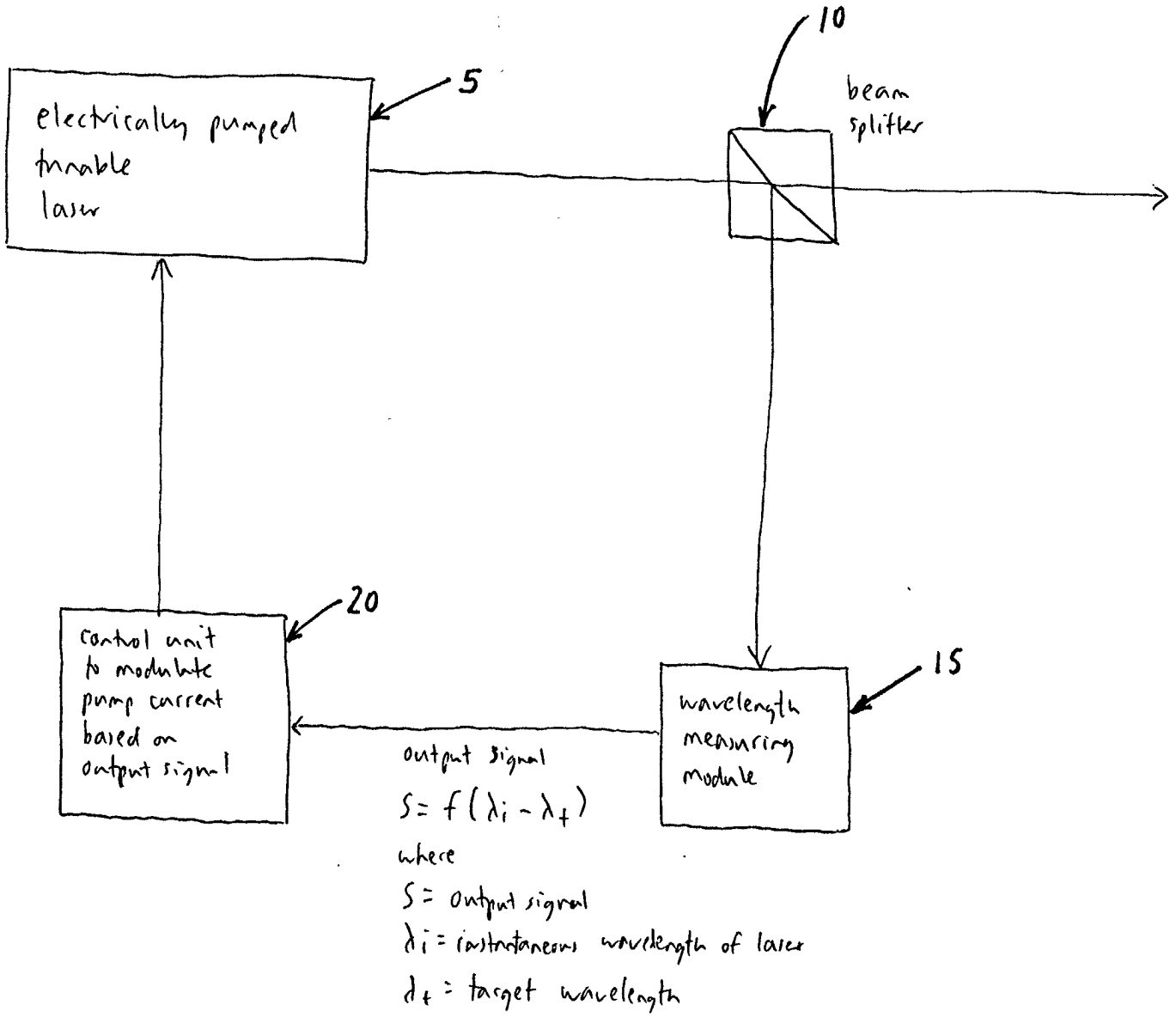
10
beam splitter
5
electrically pumped tunable laser
20
control unit to modulate pump current based on output signal
15
wavelength measuring module
output signal
$S = f(\lambda_i - \lambda_t)$
where
S = output signal
λ_i = instantaneous wavelength of laser
λ_t = target wavelength

FIG. 5

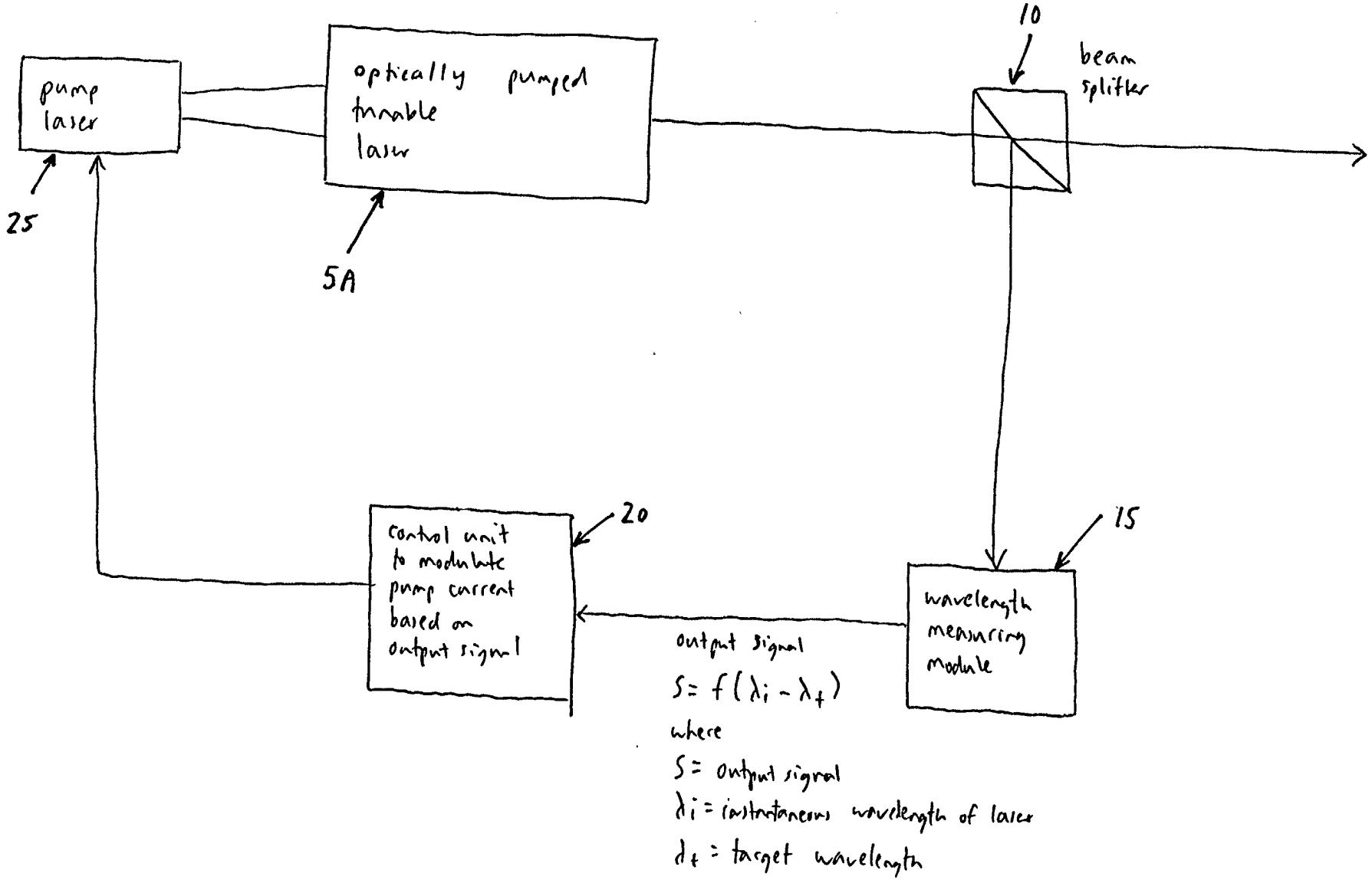
pump laser
optically pumped tunable laser
10
beam splitter
25
5A
control unit to modulate pump current based on output signal
20
wavelength measuring module
15
output signal
$S = f(\lambda_i - \lambda_t)$
where
S = output signal
λ_i = instantaneous wavelength of laser
λ_t = target wavelength

FIG. 6

DECLARATION AND POWER OF ATTORNEY

As a below-named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled "WAVELENGTH STABILIZATION OF TUNABLE LASERS BY CURRENT MODULATION", the specification of which is filed herewith, and is identified by Attorney's Docket No. CORE-61.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims.

I acknowledge the duty to disclose information which is material to the examination of this

application in accordance with Title 37, Code of Federal Regulations, Section 1.56(a).

I hereby claim priority benefits under Title 35, United States Code, Section 119(e), of U.S. Provisional Patent Application Serial No. 60/161,499, filed 10/26/99 for WAVELENGTH STABILIZATION OF TUNABLE LASERS BY CURRENT MODULATION.

I hereby appoint Pandiscio & Pandiscio, a firm composed of Nicholas A. Pandiscio, Registration No. 17293, Mark J. Pandiscio, Registration No. 30883, Scott R. Foster, Registration No. 20570, and James A. Sheridan, Registration No. 43,114, or any of them, of 470 Totten Pond Road, Waltham, Massachusetts 02451-1914, (Telephone No. 781-290-0060), my attorneys with full power of substitution and revocation, to prosecute this application and to transact all business in the U.S. Patent and Trademark Office connected therewith.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true;

and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Inventor's signature: _____

Inventor's full name: Parviz Tayebati

Date: _____

Residence: 2 Commonwealth Avenue, 15A
Boston, Massachusetts 02116

Post office address: same

Citizenship: United States

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